AEDC-TSR-82-P40

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TESTS OF THE SPACE SHUTTLE'S ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION

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Calspan Field Services, Inc.

December 1982

Final Report for Period 29 October 1982 - 4 November 1982

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This report has been reviewed and approved.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A test program was conducted in the Propulsion Wind Tunnel (16T) to demonstrate the Advanced Flexible Reusable Surface Insulation (AFRSI) joint fix designs adequacy to preclude pre-entry gaps. Representative sections of the AFRSI joints were tested at Mach numbers from 0.40 to 0.88.

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NOMENCLATURE

AFRSI	Advanced Flexible Reusable Surface Insulation
CP	Pressure coefficient, CP = $\left(\frac{P_i - P}{Q}\right)$
CONF. NO.	Configuration number
DELPI	Primary input deletion and selection code
DP	Selected differential pressure, psf
DTDPS	Difference between test section static and dew-point temperature, °F
H	Simulated geopotential altitude, ft
HR	High response
HREFP	High-response reference pressure, psf
K	Kulite®
LEF	Leading edge flap, deg
M	Free-stream Mach number
P	Free-stream static pressure, psfa
$P_{101-214}$	Test fixture pressure nomenclature, CP
PC	Tunnel plenum pressure, psfa
PCP_{15-36}	Calibration panel pressure nomenclature (Statham® transducers), CP
PK_{1-14}	Test fixture Kulite® pressure nomenclature, CP
$PKRMS_{1-14}$	Test fixture Kulite® root-mean-square pressure, psi
PN, Point	Point number (a single record of all test parameters)
PREF	Pressure reference, psf
$PSRMS_{15-36}$	Calibration panel root-mean-square pressure (Statham® transducers), psi
PT	Free-stream total pressure, psfa
Q	Free-stream dynamic pressure, psf

Re x 10-6	Free-stream unit Reynolds number times 10^{-6}, 1/ft
Run, RN	Run number (a data subset containing variations of one independent parameter)
SHx10+3	Tunnel specific humidity times 10^{+3}
TDP	Dewpoint temperature, °F
TPR	Tunnel pressure ratio
TT	Tunnel total temperature, °F
TTR	Tunnel absolute total temperature, °R
WA	Test section average wall angle, deg

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E01, Control Number 9E01, at the request of the National Aeronautics and Space Administration (NASA/JSC ES2). The NASA project manager was Mr. Jack Barneburg and the Rockwell International project engineer was Mr. Dick Kingsland. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the Propulsion Wind Tunnel (16T) during the period from October 29, 1982 through November 4, 1982, under AEDC Project Number CA25PG (PG-1X), Test Number TF645.

The purpose of the test was to demonstrate the Space Shuttle's Advanced Flexible Reusable Surface Insulation (AFRSI) joint fix designs adequacy to preclude pre-entry gaps. The test was conducted at Mach numbers from 0.4 to 0.88 at tunnel total pressures from 1600 to 2327 psfa. Steady-state and high-response pressure data, lapse time photography (4 frames per second), and video tapes were recorded throughout the test.

The purpose of this report is to document the test and describe the test parameters. The report provides information to permit use of the data but does not include any data analysis, which is beyond the scope of this report.

The final data package from this test has been transmitted to the National Aeronautics and Space Administration (NASA) and Rockwell International. Requests for these data should be addressed to NASA/JSC, ES2, Houston, Texas 77058. A microfilm copy of the final data is on file at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

The AEDC Propulsion Wind Tunnel (16T) is a variable density, continuous-flow tunnel capable of being operated at Mach numbers from 0.2 to 1.5 and stagnation pressures from 120 to 4000 psfa. The maximum attainable Mach number can vary slightly depending upon the tunnel pressure ratio requirements with a particular test installation. The maximum stagnation pressure attainable is a function of Mach number and available electrical power. The tunnel stagnation temperatures can be varied from about 80 to 160°F depending upon the cooling water temperature. The tunnel is equipped with a scavenging system which removes combustion products when testing with rocket motors or turbo-engines. The

test section is 16 ft square by 40 ft long and enclosed by 60-deg inclined-hole perforated walls of six-percent porosity. The general arrangement of the test section and the test article location is shown in Fig. 1. Additional information about the tunnel, its capabilities, and operating characteristics is presented in Ref. 1.

2.2 TEST ARTICLE

The test article, designated Model 129-0, contains three AFRSI specimen panels. The AFRSI specimens were tested for application to several areas of the Space Shuttle, using the Model 96-0 test fixture. Model 129-0 also included a calibration panel which was used to determine the tunnel and fixture conditions necessary to produce the desired aerodynamic test conditions for the AFRSI specimens.

The Model 96-0 test fixture, Fig. 2, utilized endplates to create a two-dimensional flow field on the fixture test area. The endplates (98-in. long by 56-in. high) extended from a height of 3 ft above the top of the test panel to the floor, and were supported beneath the floor. The beveled leading edges were located 26 in. forward of the test specimen leading edge. A full span flap located at the leading edge of the test fixture was used to produce the desired expansion/recompression shock waves on the test panel's surface. The hydraulically actuated flap rotated through angles of zero to 30 deg (leading edge down).

The calibration panel, Fig. 3, which is used to determine the tunnel and fixture conditions, is interchangeable with the three AFRSI test panels, Figs. 4 through 6. The AFRSI test panels (designated ND-14-1, ND-14-2, and ND-14-3) each incorporated several of the various gap fix designs illustrated in Fig. 7. Each test specimen includes a support plate, the AFRSI material bonded to the support plate, and a frame which protects and holds the AFRSI edges. Installed, the frame of the test specimen is flush with the adjacent surfaces of the test fixture.

A more detailed description of the test article is given in Ref. 2.

2.3 INSTRUMENTATION

A total of forty-two (42) steady-state pressure measurements were made for orifices located on the Model 96-0 test fixture (28 AEDC-supplied Setra® and 14 Rockwell International-supplied Kulite® transducers (Fig. 8). In addition, twenty-two (22) steady-state pressure measurements were made for orifices located on the Model 129-0 calibration panel, using Statham transducers supplied by Rockwell International (Fig. 9).

Output from the Kulite® and Statham® pressure transducers were recorded on magnetic tape by a constant bandwidth, multiplexed, frequency modulated (FM) recording system. The high-response signals from the Kulites® and Stathams® were also parallel to RMS-to-DC converters which were filtered with 4 kHz (-3 db point) 2-pole active, low pass filters. The outputs of the RMS-to-DC converters were included in the steady-state data acquisition.

The leading edge flap angular position was measured using a potentiometer. Primary instrumentation also included lapse time photography at 1/4 real time, video tapes, and still photographs of the AFRSI test panel before and after each test period. Complete model instrumentation details may be found in Ref. 2.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

The test was conducted at Mach numbers from 0.40 to 0.88 at tunnel total pressures from 900 to 2327 psfa. A summary of the nominal test conditions is listed in Table 1 and the test program run number summary is given in Table 2.

Data for the Model 129-0 calibration panel were recorded at the tunnel conditions and leading edge flap positions specified in Table 2. For each data point, 30 sec of high-response data (Kulite® and Statham® outputs) were recorded on FM multiplexed tape. However, data for each AFRSI specimen panel were acquired using two different data acquisition modes.

First, each AFRSI panel was subjected to the scheduled test conditions just long enough to conduct a Mach number sweep from 0.0 to 0.82 (approximately 3.5 min at a tunnel dynamic pressure (Q) above 400 psf). During this mode of operation, data were continuously recorded on the FM multiplexed tape recording, lapse time photography, and video tape recording systems from wind-on to wind-off conditions. Also, steady-state data points were acquired at approximately 10 to 12 sec intervals during the air-on period. After the tunnel was shut down the AFRSI panel was inspected and photographed.

Second, the AFRSI panel was subjected to another test which represented a hundred (100) cycle mission. The specimens were tested at the scheduled tunnel conditions (cycling between Mach 0.74 to 0.82) for a total cumulative time of approximately 42 min at Q above 400 psf. During this mode of operation, data were also continuously recorded as previously described. However, once the Mach 0.74 test conditions were established, steady-state data were recorded at 0.02 Mach increments between Mach 0.74 and 0.82.

Prior to each test period, all pressure transducers and the leading edge flap were calibrated. Additionally, the high-response transducers were also calibrated during and following the completion of each test period. The high-response transducer measurements, as recorded by the multiplexed FM tapes, were monitored during the test period using an oscilloscope and a spectral analyzer supplied by Rockwell International.

All steady-state measurements were sequentially recorded by the facility on-line computer system, which reduced the data to engineering units, further processed the data to obtain the required model parameters, tabulated the data in the Tunnel 16T control room, recorded the data on magnetic tape, and transmitted the data to the AEDC central computer file. The data stored in the central computer file were generally available for plotting and analysis on the PWT Interactive Graphics System within 30 seconds after data acquisition. The immediate availability of the tabulated and plotted data permitted continual on-line monitoring of the test results. The leading edge flap angle and other critical test parameters were input to the real-time digital data acquisition system. The real-time measurements aided setting of the desired model conditions and facilitated the progress of the test.

Sample data plots from the Model 129-0 calibration panel orifices are presented in Fig. 10. Figure 10 is indicative of the on-line plotting capabilities available in Tunnel 16T.

3.2 DATA REDUCTION

The test article pressure data were presented in terms of pressure coefficient, CP, for the 22 calibration panel and 42 test fixture pressure measurements. RMS pressure fluctuations, in psi, were also calculated for the 22 calibration panel (Statham®) and the 14 test fixture (Kulite®) transducers. The leading edge flap deflection was presented in degrees, positive leading edge down.

3.3 UNCERTAINTY OF MEASUREMENTS

Uncertainties (combinations of systematic and random errors) of the basic tunnel parameters, shown in Fig. 11, were estimated from repeat calibration of the instrumentation and from the repeatability and uniformity of the test section flow during tunnel calibration. Uncertainties in the instrumentation systems were estimated from repeat calibration of the systems against secondary standards whose uncertainties are traceable to the National Bureau of Standards calibration equipment. The instrument uncertainties, for a 95% confidence level, are combined using the Taylor series method of error propagation described in Ref. 3 to determine the uncertainties of the reduced parameters shown in Table 3. The data uncertainties for the transducers supplied by Rockwell International are unavailable. The repeatability of the data is shown in Fig. 12. The data indicate that the repeatability is of the order of the quoted uncertainty.

4.0 DATA PACKAGE PRESENTATION

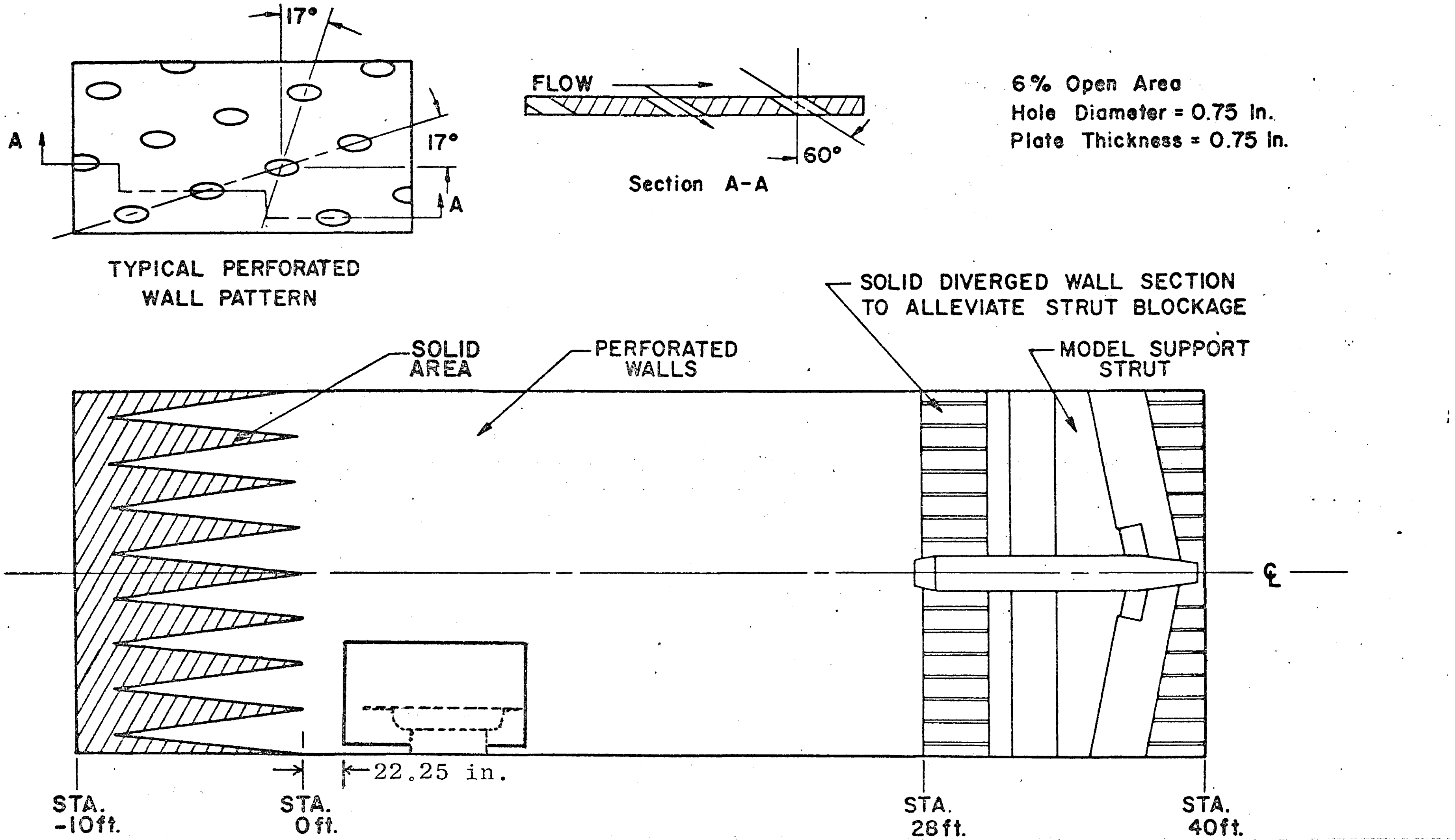
The data package contained: 1) tabulated data sheets listing all test parameters, 2) digital magnetic computer tapes of the steady-state information, 3) test article photographs, 4) time lapse photography of the test panels, 5) video tapes of the test panels, 6) analog FM tapes, and 7) appropriate test logs for identification of the test runs, test conditions, and test article configurations. An example of the tabulated data is shown in Table 4. The parameters are identified in the nomenclature of this report.

REFERENCES

1. Test Facilities Handbook (Eleventh Edition). "Propulsion Wind Tunnel Facility, Vol. 4." Arnold Engineering Development Center, April 1981.

2. Marshall, B. A. "Pretest Information for the AFRSI Gap Fix Test OS-313 in the AEDC/USAF 16T Transonic Wind Tunnel Using Model 129-0 Installed in the Model 96-0 Test Fixture." Rockwell International/Space Division, STS 82-0747, October 1982.

3. Abernethy, R. B. and Thompson, J. W., Jr. "Handbook - Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD755356), February 1973.



NOTE: Test article and support system not drawn to scale.

Figure 1. Test Article Location in Tunnel 16T

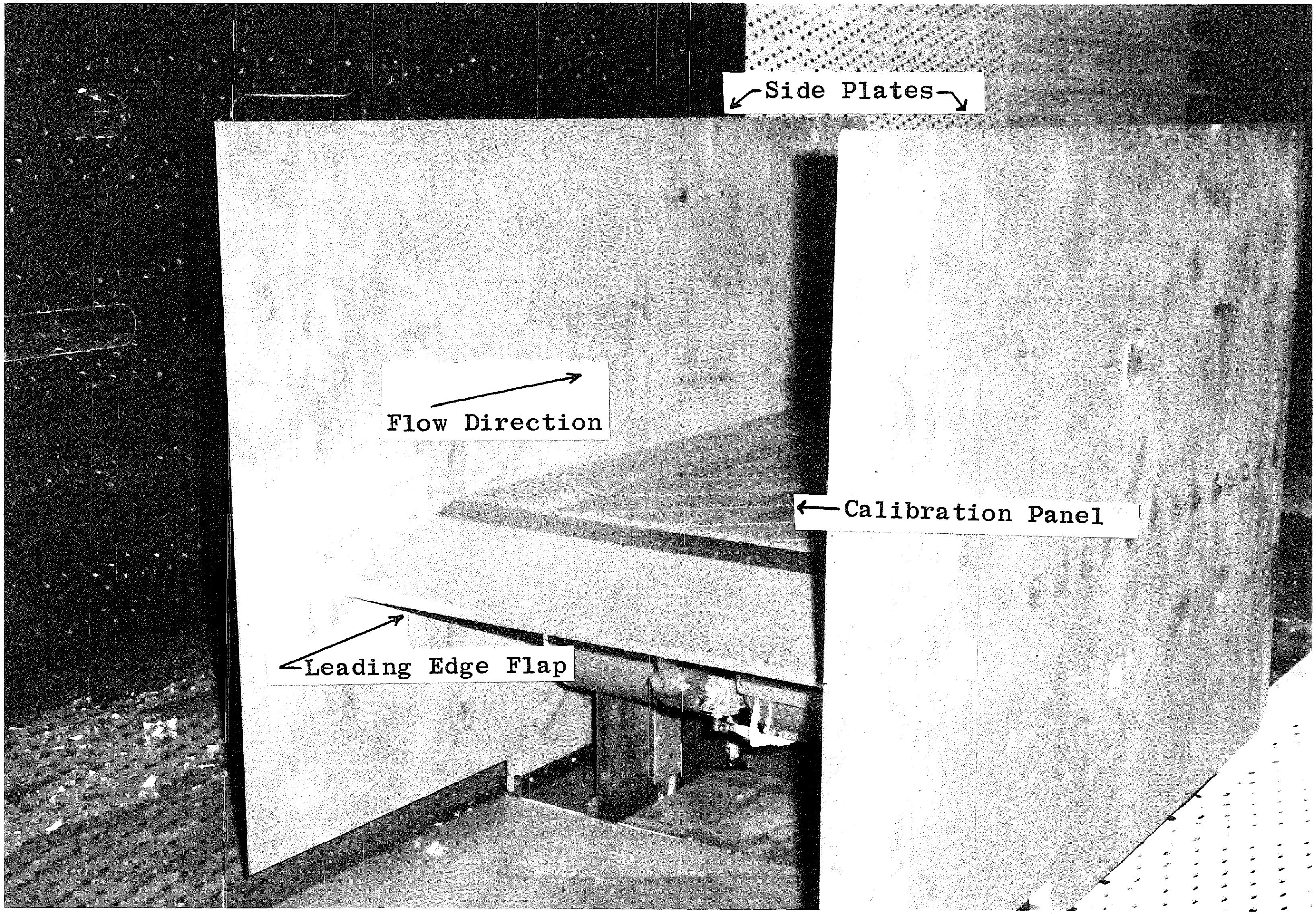


Figure 2. Model 96-0 Test Fixture Installation in Tunnel 16T

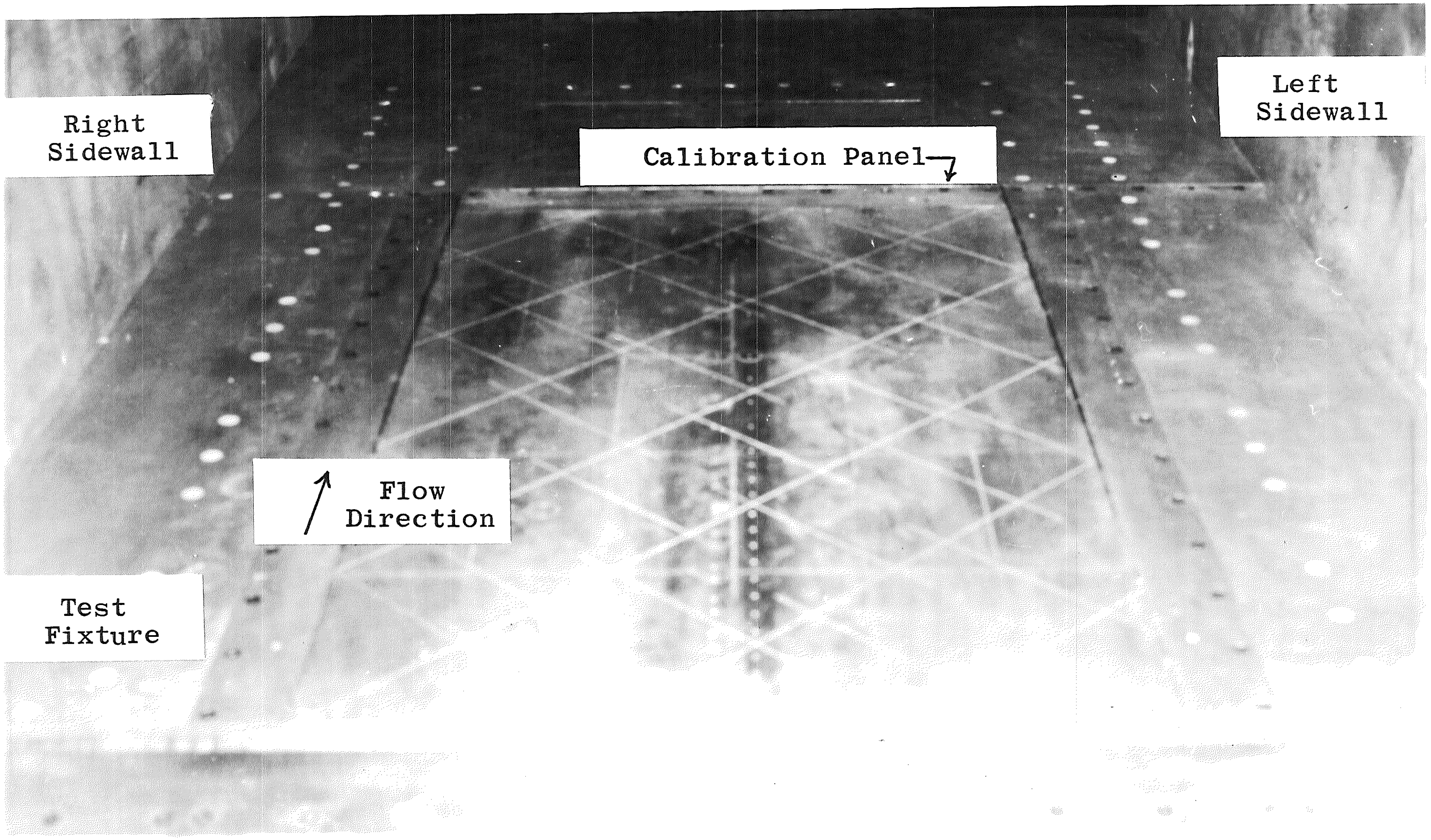
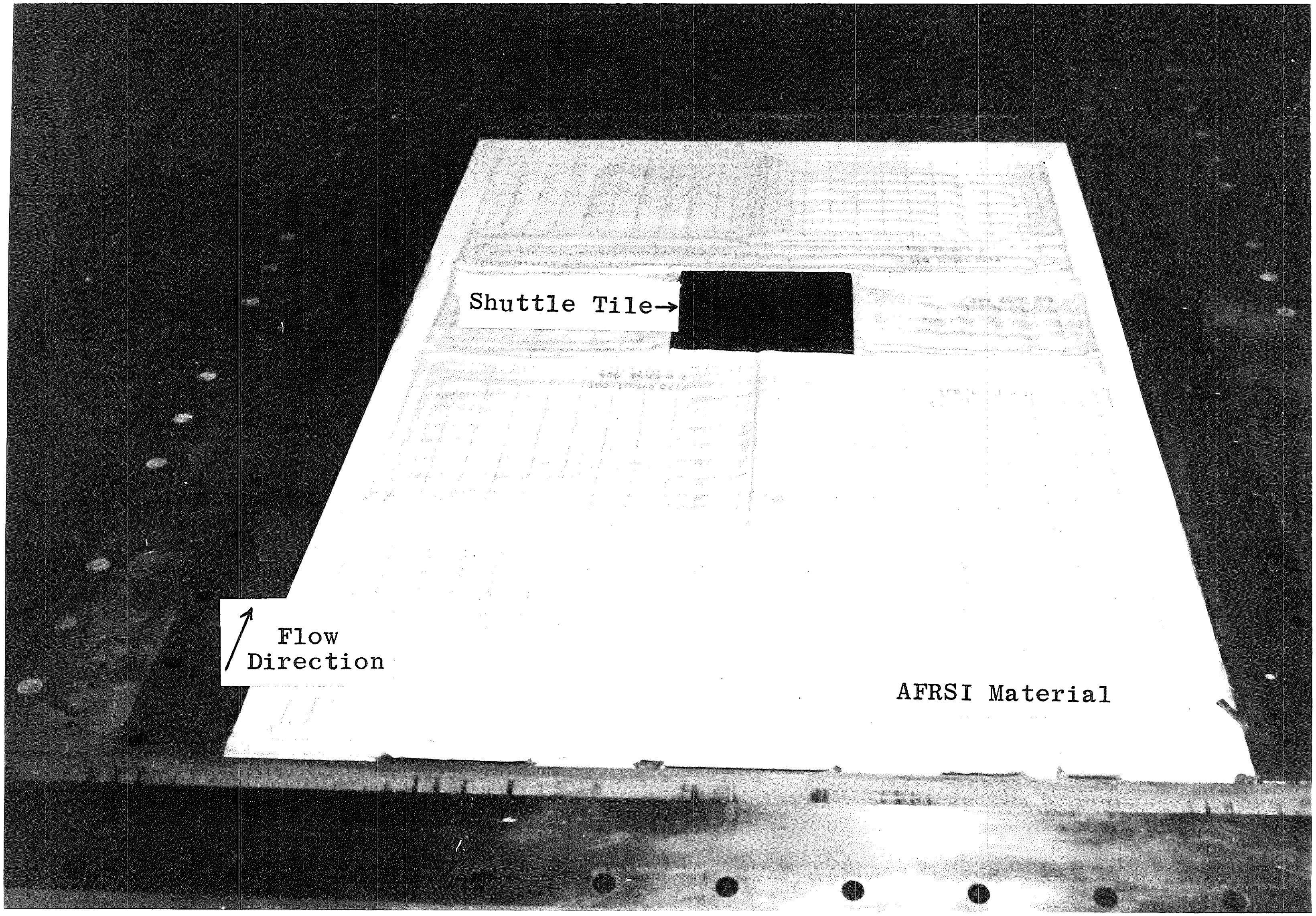
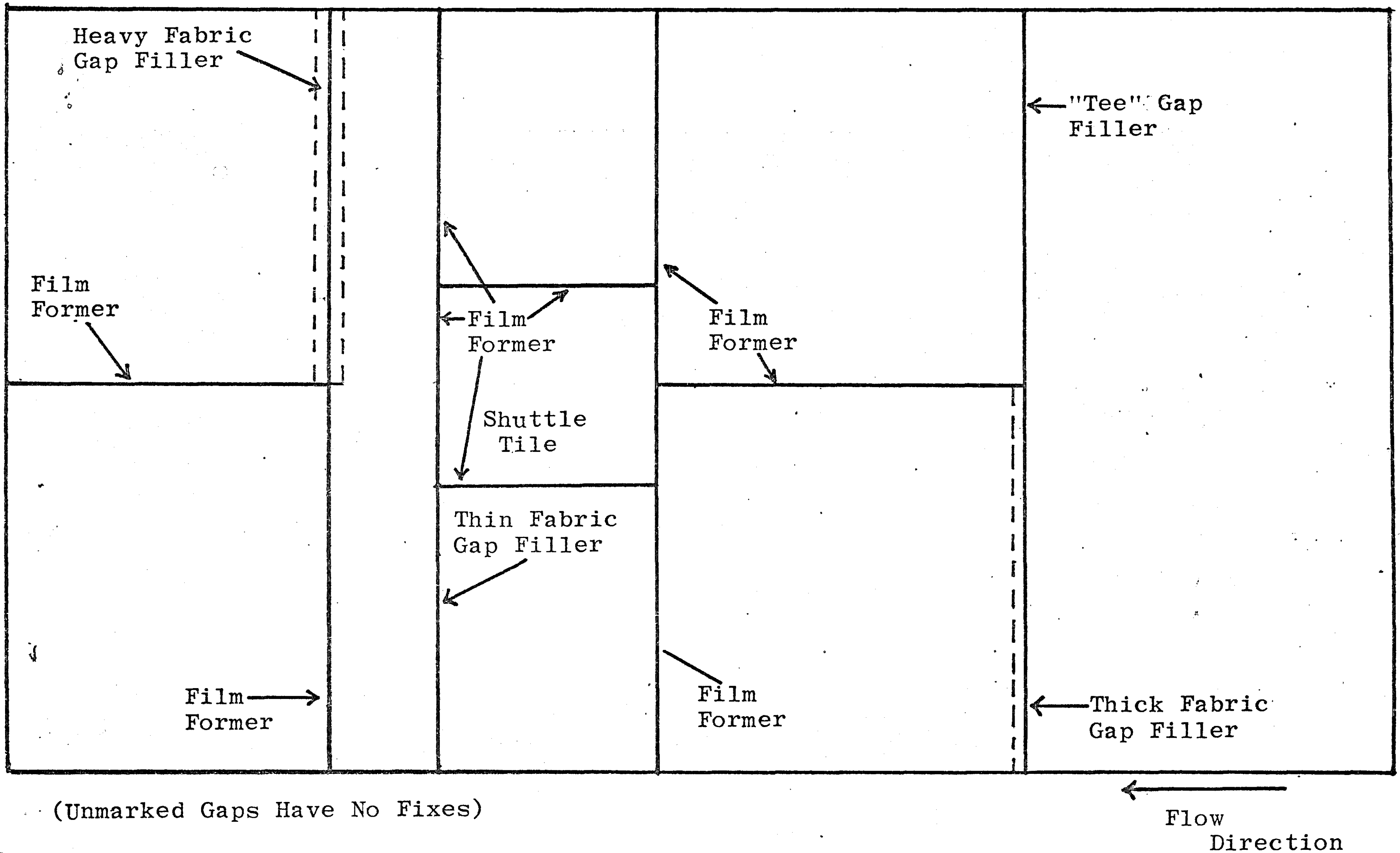


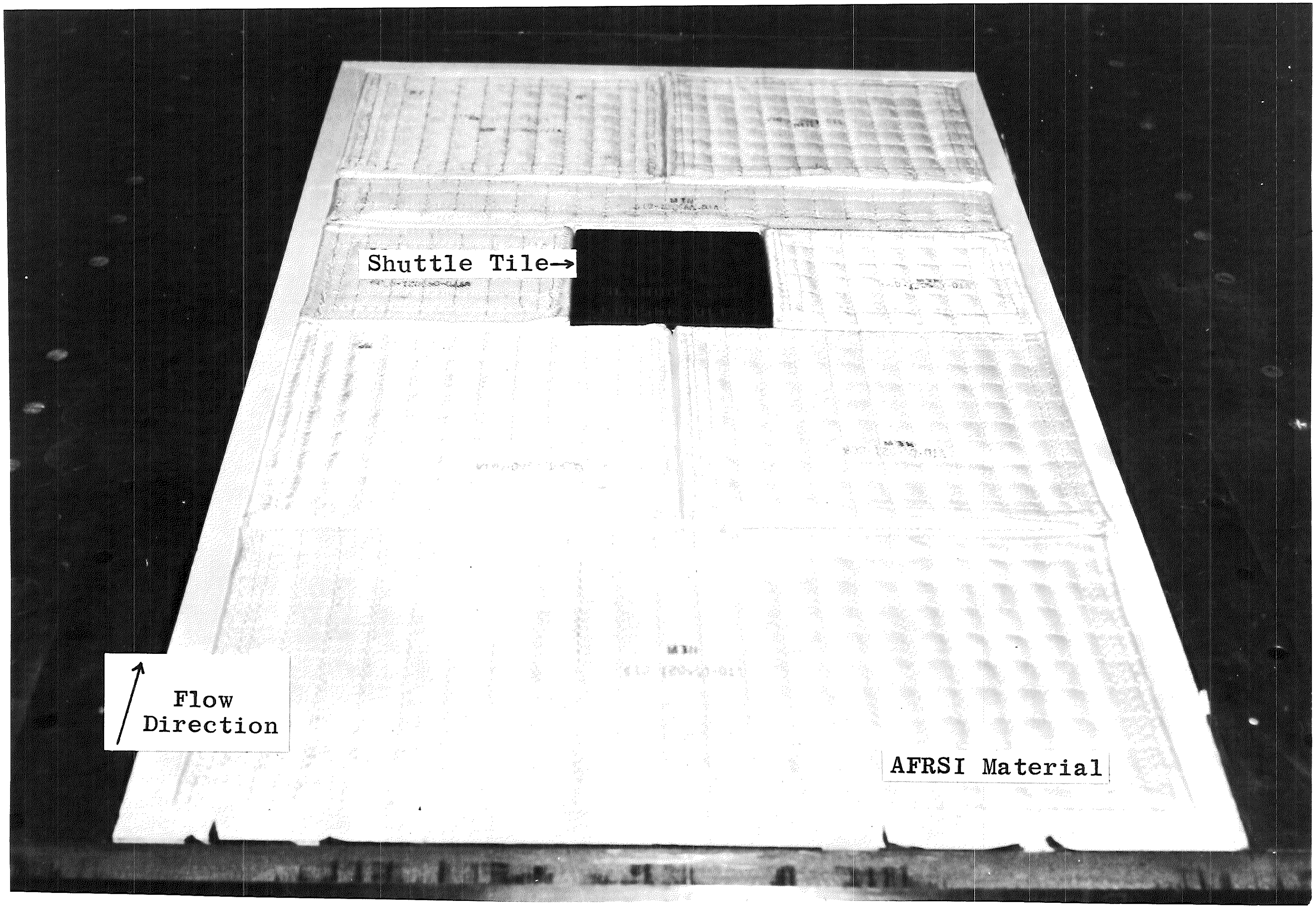
Figure 3. Model 129-0 Calibration Panel



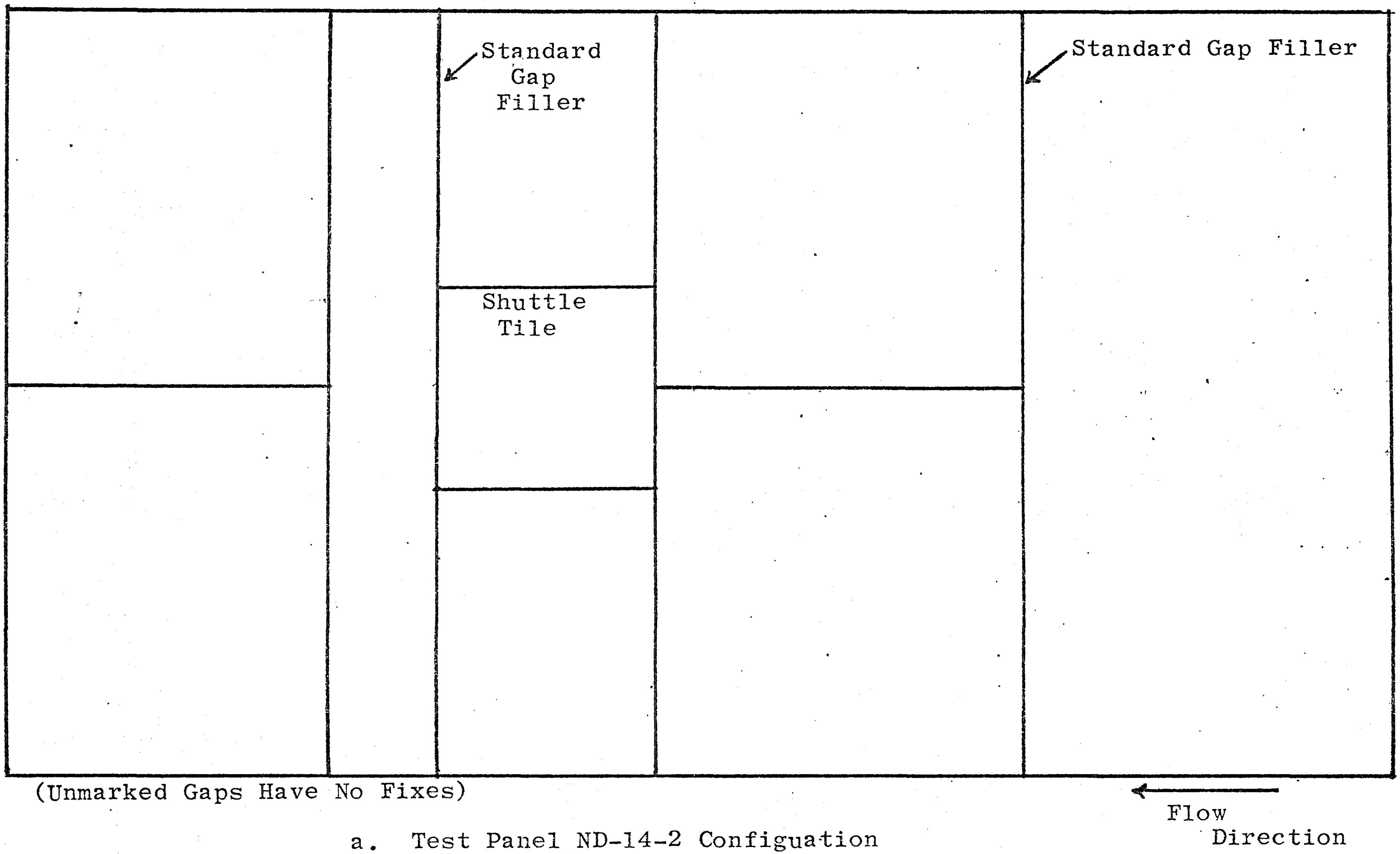
a. Test Panel Installed in Test Fixture
Figure 4. AFRSI Test Panel ND-14-1



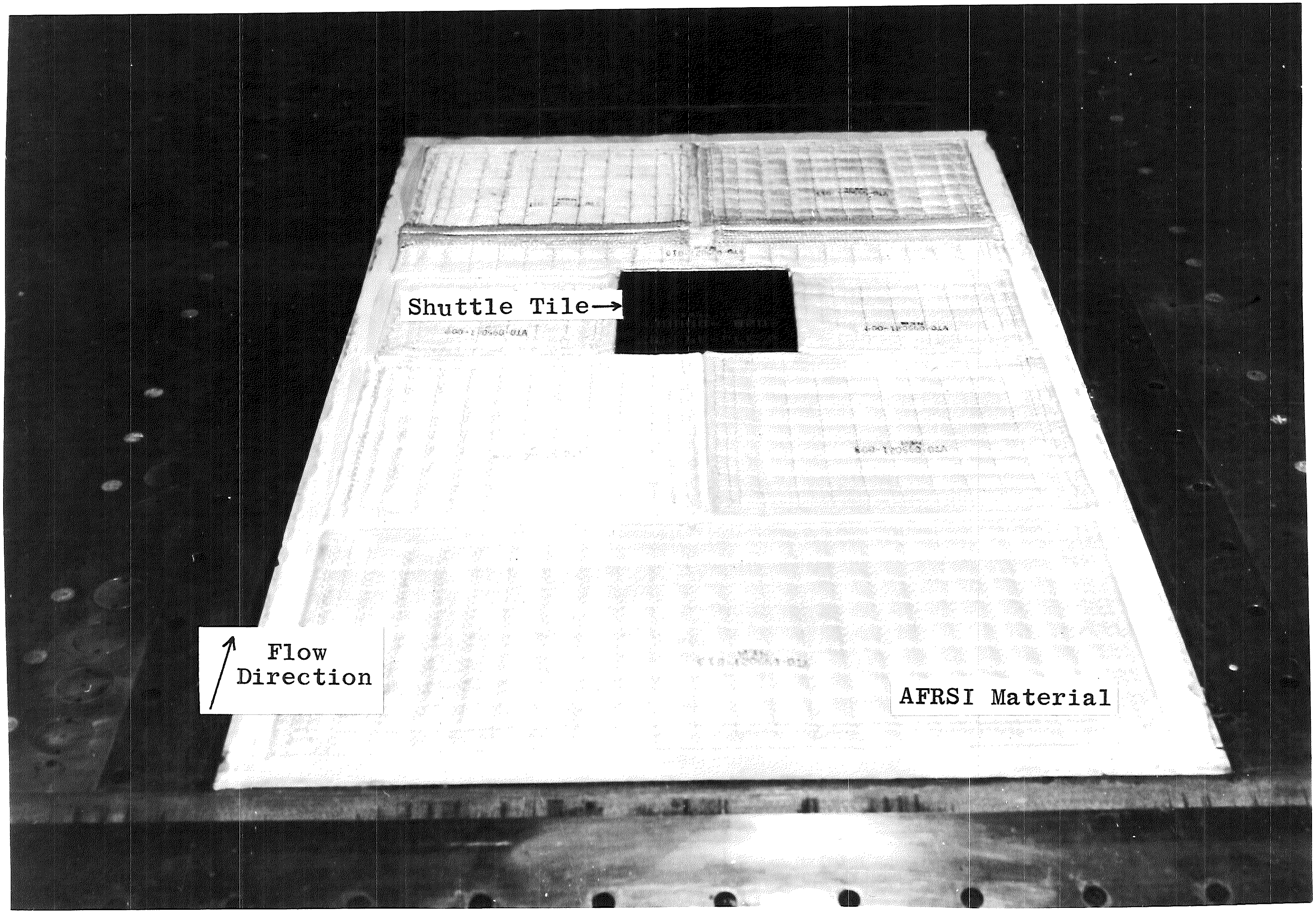
b. Test Panel ND-14-1 Configuation
Figure 4. Concluded



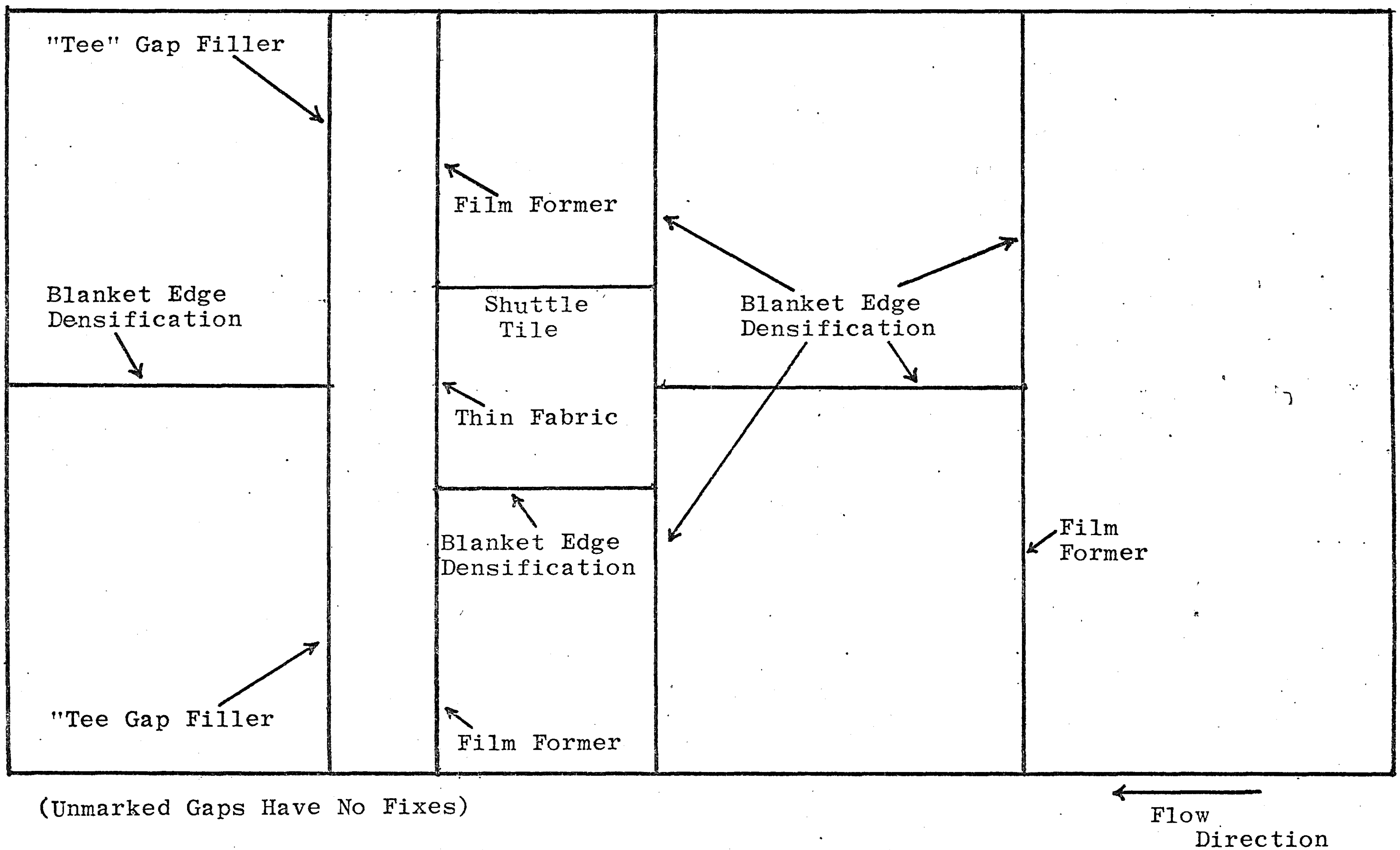
a. Test Panel Installed in Test Fixture
Figure 5. AFRSI Test Panel ND-14-2



a. Test Panel ND-14-2 Configuation
Figure 5. Concluded



a. Test Panel Installed in Test Fixture
Figure 6. AFRSI Test Panel ND-14-3



b. Test Panel ND-14-3 Configuation
Figure 6. Concluded

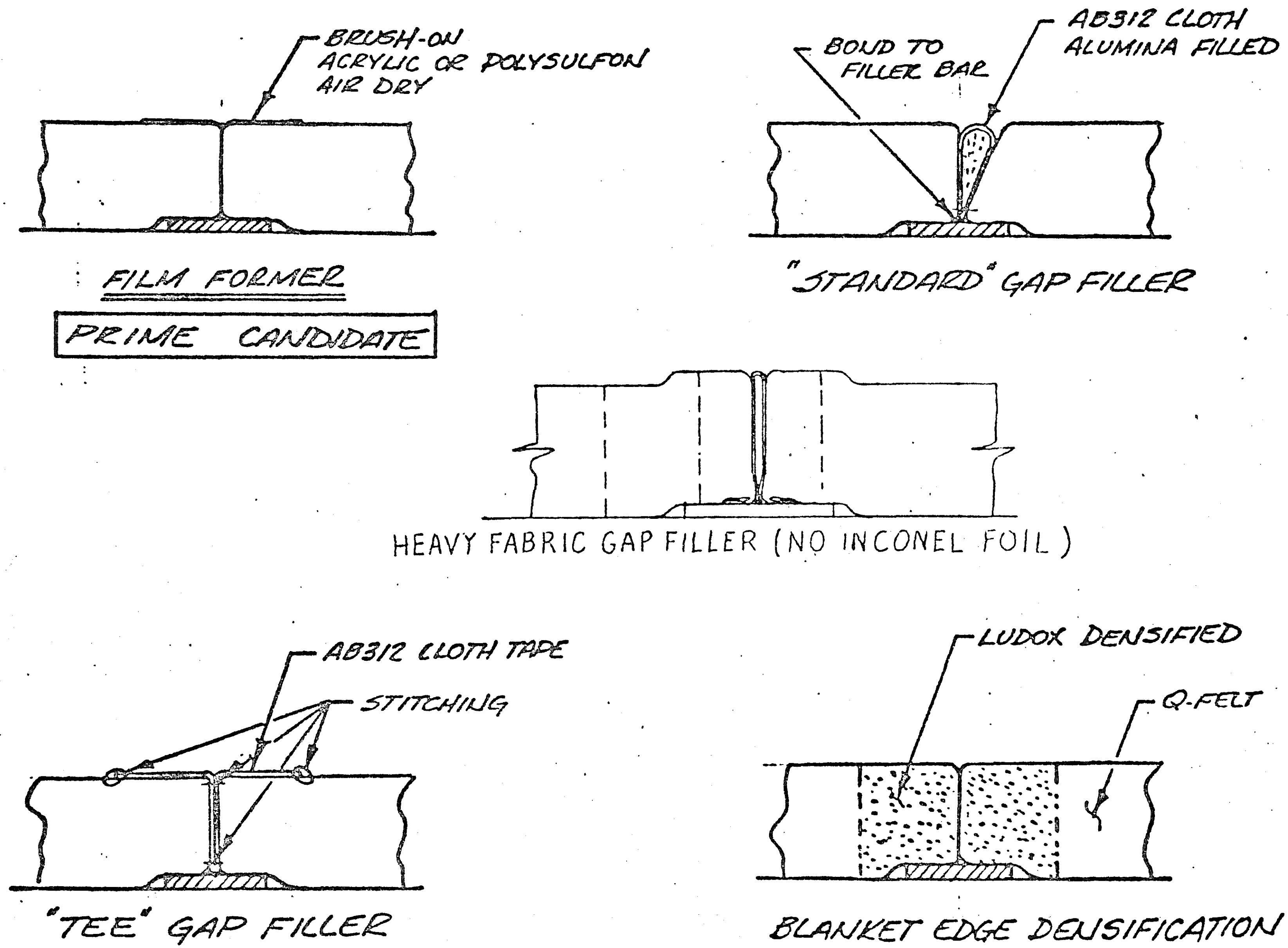


Figure 7. Candidate Designs-AFRSI Joints to Preclude Gaps

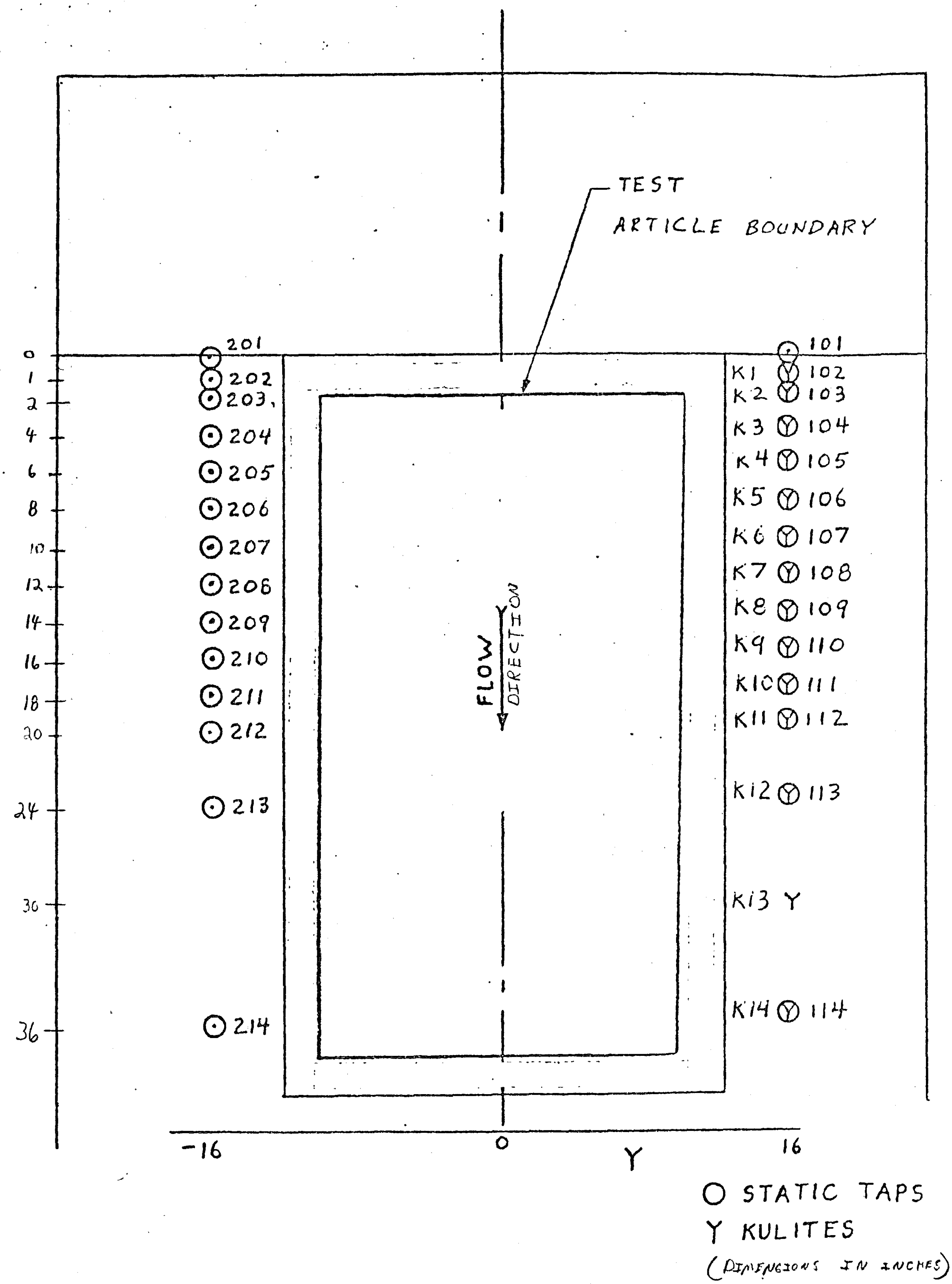
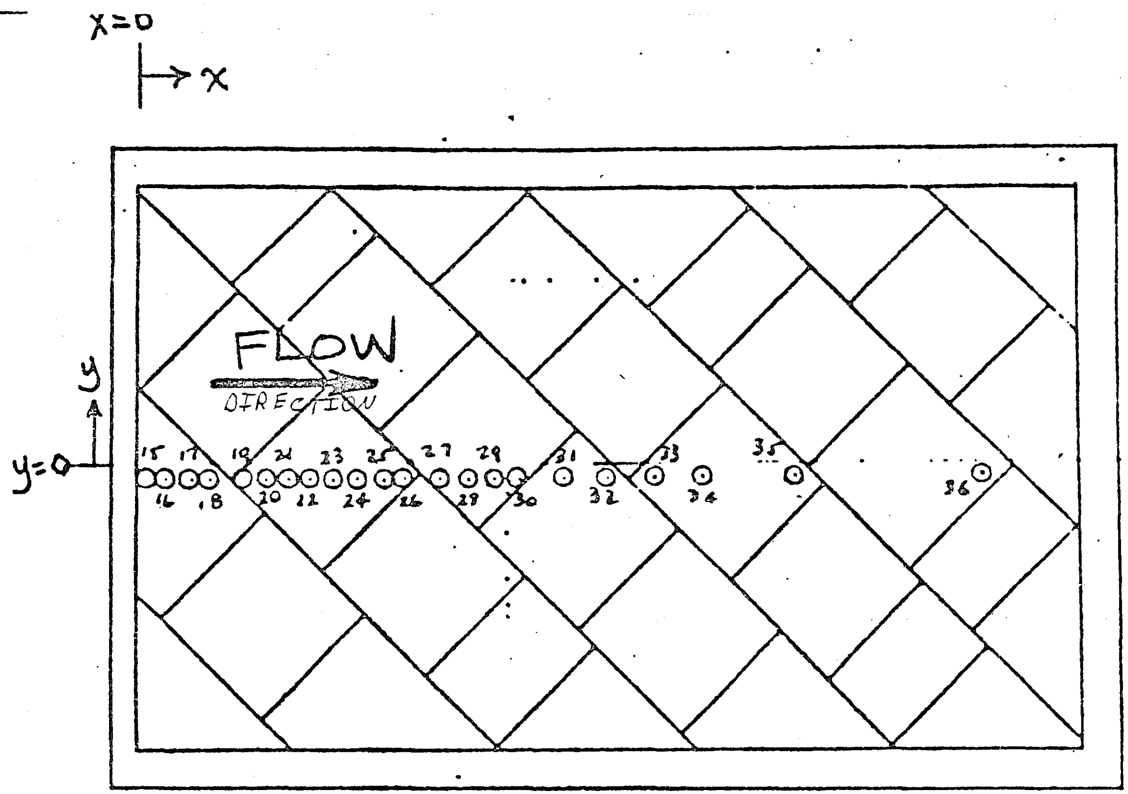


Figure 8. Model 96-0 Test Fixture Pressure Orifice Locations



TAP* NO.	X** (IN)	Y (IN)
15	0.50	-0.625
16	1.40	-0.625
17	2.30	-0.625
18	3.20	-0.625
19	4.50	-0.625
20	5.53	-0.625
21	6.56	-0.625
22	7.59	-0.625
23	8.62	-0.625
24	9.65	-0.625
25	10.68	-0.625
26	11.71	-0.625
27	13.04	-0.625
28	14.11	-0.625
29	15.18	-0.625
30	16.25	-0.625
31	18.12	-0.625
32	20.12	-0.625
33	22.12	-0.625
34	24.12	-0.625
35	28.12	-0.625
36	36.12	-0.625

* TAP NOS. FROM TEST

** APPROXIMATE LOCATION

Figure 9. Model 129-0 Calibration Panel Pressure Orifice Locations

RUN 30

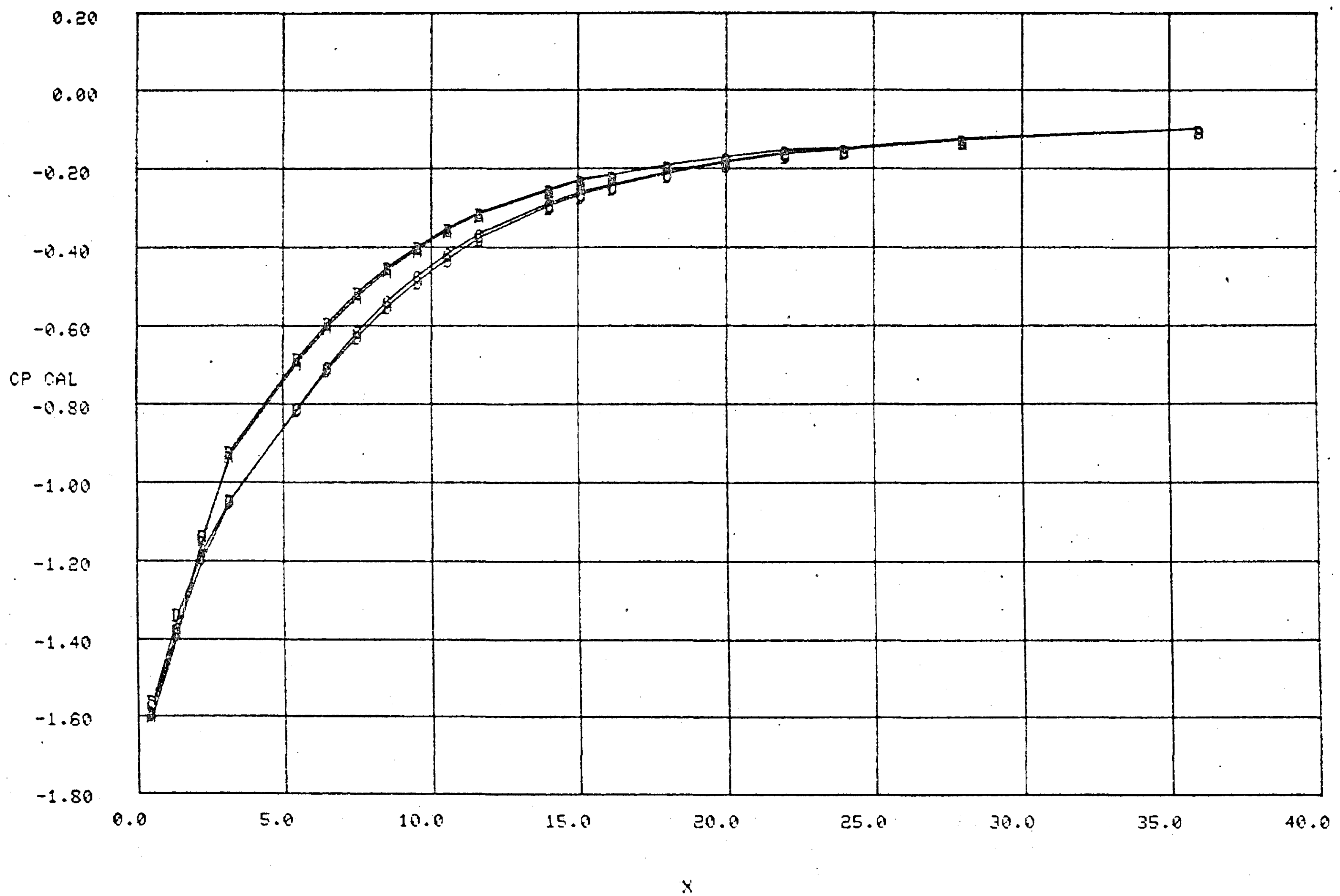


Figure 10. Sample Data Plot

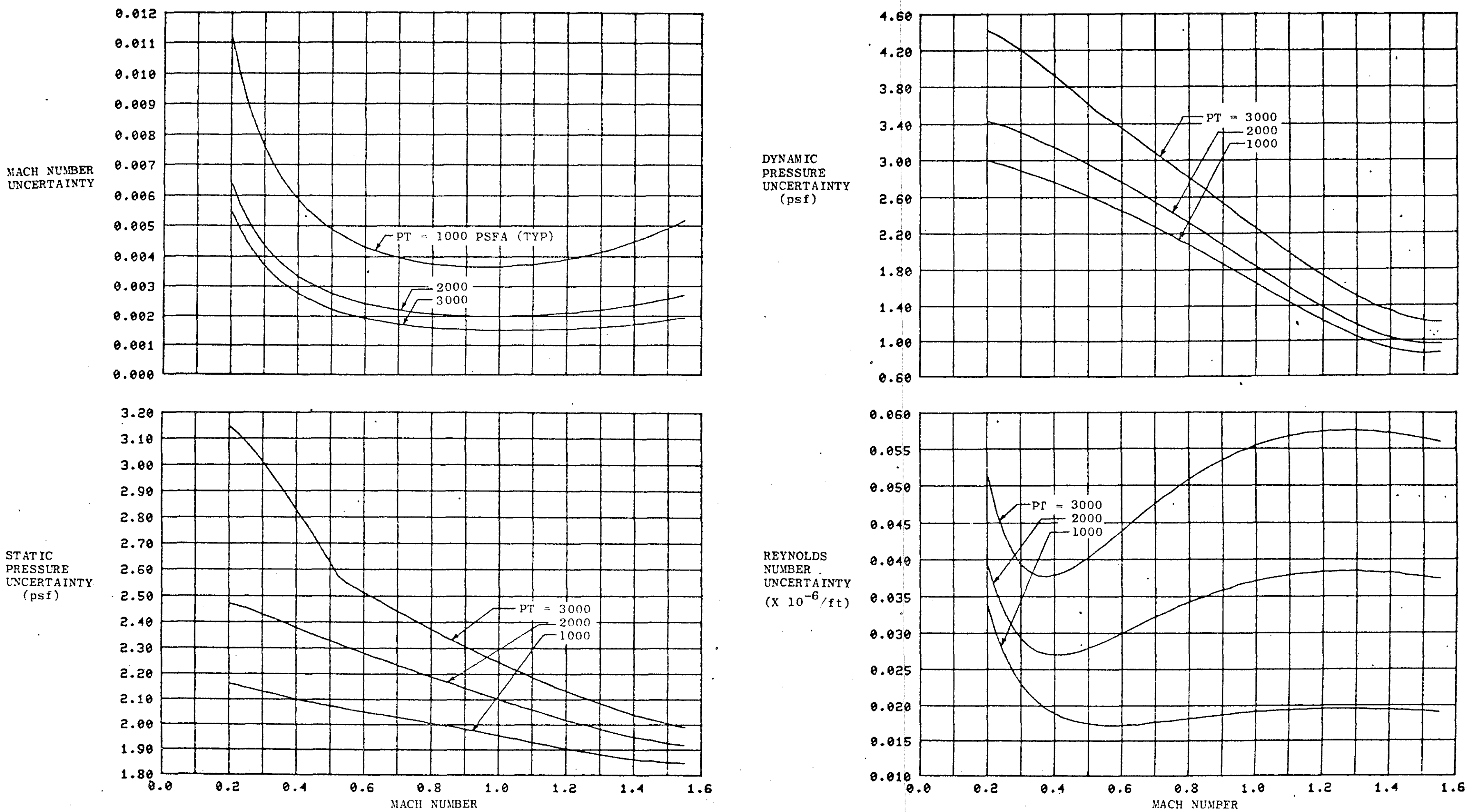


Figure 11. Estimated Uncertainties in Wind Tunnel Parameters

RUN 29 (a comparison of data points 1 and 2)

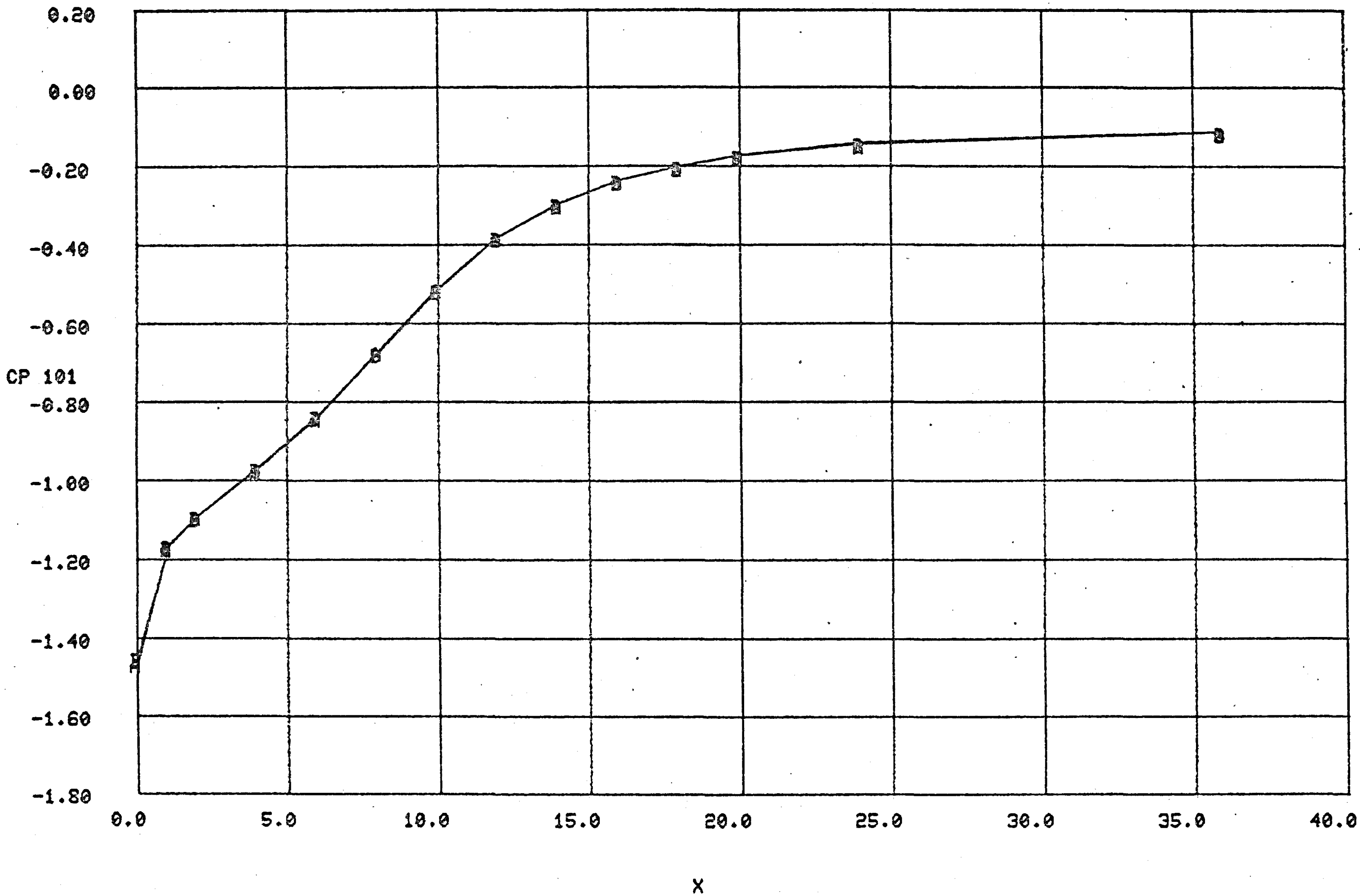


Figure 12. Data Repeatability

Table 1. Nominal Test Conditions

Mach No.	PT psfa	Q psf	P psfa	Re x 10^{-6} 1/ft	TT °F
0.40	1600	159.8	1433	1.883	80
0.60	1600	316.1	1254	2.511	80
0.70	2327	574.5	1680	4.041	100
0.72		597.9	1652	4.128	
0.74		619.3	1621	4.191	
0.76		641.3	1587	4.250	
0.78		665.5	1558	4.313	
0.80		682.4	1528	4.342	
0.82		702.8	1497	4.409	
0.84		723.6	1466	4.447	
0.86		743.5	1434	4.499	
0.88		761.1	1406	4.515	

Table 2. Run Number Summary

Run	M	PT	LEF	Configuration	Comments
21	0.80	2327	Vary	4	Calibration Panel Data
22	0.84				
23	0.88				
24	0.86				
25	0.82				
26	0.78				
27	0.76				
28	0.74				
29	0.72				
30	0.70				
31	0.60	1600			
32	0.40	1600			
42	0.74 → 0.82	1900 → 2000	18.0	2	1 cycle run;panel ND-14-2
48				2	Multi-cycle run; panel ND-14-2
54				3	1 cycle run; panel ND-14-3
59				3	Multi-cycle run; panel ND-14-3
67				1	1 cycle run; panel ND-14-1
72				1	Multi-cycle run; panel ND-14-1

Table 3. Uncertainties of Critical Test Parameters

M	CP101	CP114	LEF
0.70	±0.00716	±0.00393	±0.10
0.76	±0.00693	±0.00350	
0.82	±0.00579	±0.00314	
0.88	±0.00495	±0.00283	

DATE. 12- 1-82 PROJECT NO. P41G-1X
ARVIN/CALSPAN FIELD SERVICES. INC.
AEDC DIVISION
PROPULSION WIND TUNNEL
ARNOLD AIR FORCE STATION. TENNESSEE

Table 4. Tabulated Data

RUN	PN	PROJECT	TEST	DATE	DAY HR MIN SEC	MODE	DELPI	PROD DATE	WINDOFF	SET	CART	TRANSONIC 16T
20	1	P41G-1X	TF-645	11/ 2/82	306: 1: 3:35	0/ 0	1280	12-0 1-82	19/ 1	26	2.	

M	PT	P	Q	REX10-6	TT	TTR	H	PC	DP	WA	TPR	SHX10+3	TOP	DTOPS
0.0	1492.8	1493.4	1.0	0.081	74.1	533.8	9337.	1493.4	-0.6	-0.00	1.000	2.681	17.4	56.7

LEADING EDGE FLAP	HR CAL RUN	HREFP	CONF. NO.
17.916	15.	1492.33	4

*** TEST FIXTURE ***

	Y=-16	CP S		Y=+16	
(NO)	P201-214	(XX)	P101-114	PK1-PK14	PKRMS1-14
(01)	1.81787	(00)	0.33521	9.99999	99.9999
(02)	2.49414	(01)	-0.06934	-0.86646	0.0003
(03)	2.22510	(02)	0.06543	-1.43359	-0.0262
(04)	0.60425	(04)	0.33643	0.20459	-0.0214
(05)	1.81812	(06)	0.47388	-0.68433	-0.0074
(06)	1.01025	(08)	0.06494	-0.08447	0.0073
(07)	1.54883	(10)	0.06543	-1.00952	-0.0009
(08)	0.74097	(12)	0.20239	-1.07080	-0.0134
(09)	1.00977	(14)	0.33545	-0.76611	-0.0054
(10)	1.00806	(16)	0.47021	1.04688	-0.0018
(11)	0.73950	(18)	0.20044	-0.39917	0.1546
(12)	0.74048	(20)	0.19995	-1.27832	0.0062
(13)	0.47095	(24)	0.06519	-0.51270	0.0032
(14)	2.21924	(36)	0.33374	0.54370	0.0015

*** CALIBRATION PANEL ***

CP S

(NO)		PCP15-25	PSRMS15-25	(NO)		PCP26-36	PSRMS26-36
(15)	.50	-0.31665	0.0041	(26)	11.71	-0.57642	0.0117
(16)	1.40	-0.70776	0.0023	(27)	13.04	9.99999	99.9999
(17)	2.30	-0.58813	0.0268	(28)	14.11	-0.96899	0.0130
(18)	3.20	-0.44873	0.0136	(29)	15.18	-0.94360	-0.0238
(19)	4.50	9.99999	99.9999	(30)	16.25	-0.31006	0.0169
(20)	5.53	-0.59814	0.0205	(31)	18.12	-0.66870	0.0177
(21)	6.56	-0.65308	0.0114	(32)	20.12	-0.69263	0.0132
(22)	7.59	-1.15552	0.0109	(33)	22.12	-0.71948	0.0344
(23)	8.62	-0.95386	0.0322	(34)	24.12	-0.84302	0.0270
(24)	9.65	-0.96045	0.0041	(35)	28.12	-0.64722	0.0130
(25)	10.68	-0.71460	0.0107	(36)	36.12	-0.87231	0.0301